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MARINE PHYSICAL LABORATORY
of the Scripps Institution of Oceanography
San Diego, California 92132

HIGH RESOLUTION, NARROW BEAM ECHO SOUNDER

E. D. Squier, R. B. Williams, S. P. Burke
and F. H. Fisher

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This work describes the development of a high resolution echo sounder for use with the R/P FLIP. The instrument has a source level of + 227 dB/μPa, a 3 dB beam width of 1° and a receiver sensitivity of - 176 dB/μPa providing operating capabilities as a bottom sounder for water depths to 2000 m. The results of its operation at sea along with observations of acoustic returns from multiple thin scattering layers to depth of over 400 m. are included. Graphic examples under various operating conditions are presented as well as reflection coefficients measured from bottom returns and acoustic scattering target strengths.

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UNIVERSITY OF CALIFORNIA, SAN DIEGO
MARINE PHYSICAL LABORATORY OF THE
SCRIPPS INSTITUTION OF OCEANOGRAPHY
SAN DIEGO, CALIFORNIA 92132

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ABSTRACT

This work describes the development of a high resolution echo sounder for use with the R/P FLIP. The instrument has a source level of +227 dB/μPa, a 3 dB beam width of 1° and a receiver sensitivity of -176 dB/μPa providing operating capabilities as a bottom sounder for water depths to 2000 m. The results of its operation at sea along with observations of acoustic returns from multiple thin scattering layers to depth of over 400 m are included. Graphic examples under various operating conditions are presented as well as reflection coefficients measured from bottom returns and acoustic scattering target strengths.

INTRODUCTION

Recent bottom bounce data collected from the stable buoy R/P FLIP[1/] have required detailed bathymetric data in the bottom reflection area in order to measure bottom slopes in the vicinity of bottom bounce points. In this way measured vertical and horizontal angles of arrival of signals via the bottom bounce path can be related to bottom topography.

A high resolution echo sounder has been developed to fill this requirement. The echo sounder has a 3 dB beam width of 1° thus illuminating a 17.5 m diameter spot at a depth of 1 km. The plate on which the transducer array is mounted can be tilted 10° in two orthogonal directions in order to measure local bottom slopes.

The array has been used at sea mounted at 94 m depth on the R/P FLIP in the downward looking position as shown in Fig. 1. The array has also been operated with the beam pointed in a horizontal direction. When operated in this manner, the system can be used for the measurement of water particle velocity.

The details of the echo sounder system are discussed in the next section and in the last section, some experimental results from operations at sea will be presented.

I. ECHO SOUNDER SYSTEM

1. SOURCE

The source and receiving system block diagram is shown in Fig. 2; the array positioning system block diagram, in Fig. 3.

The transmitting array is made up of eight transducers placed on an aluminum plate 1.27 cm thick by 96.5 cm square (0.5" x 38" square). The transducers are constructed of four 4.6 cm square, thickness resonant, barium titanate blocks butted together. The sides and rear are backed with a pressure release material, Corprene. The unit is cast in polyurethane with an underwater cable and connector, Fig. 4.

The placement of the transducers on the aluminum plate was optimized for a 1° beam and low side lobe characteristics using a computer. The element placement on the aluminum plate is shown in Fig. 5 and the computer printout of the predicted beam pattern for the 8-element array is shown in Fig. 6.

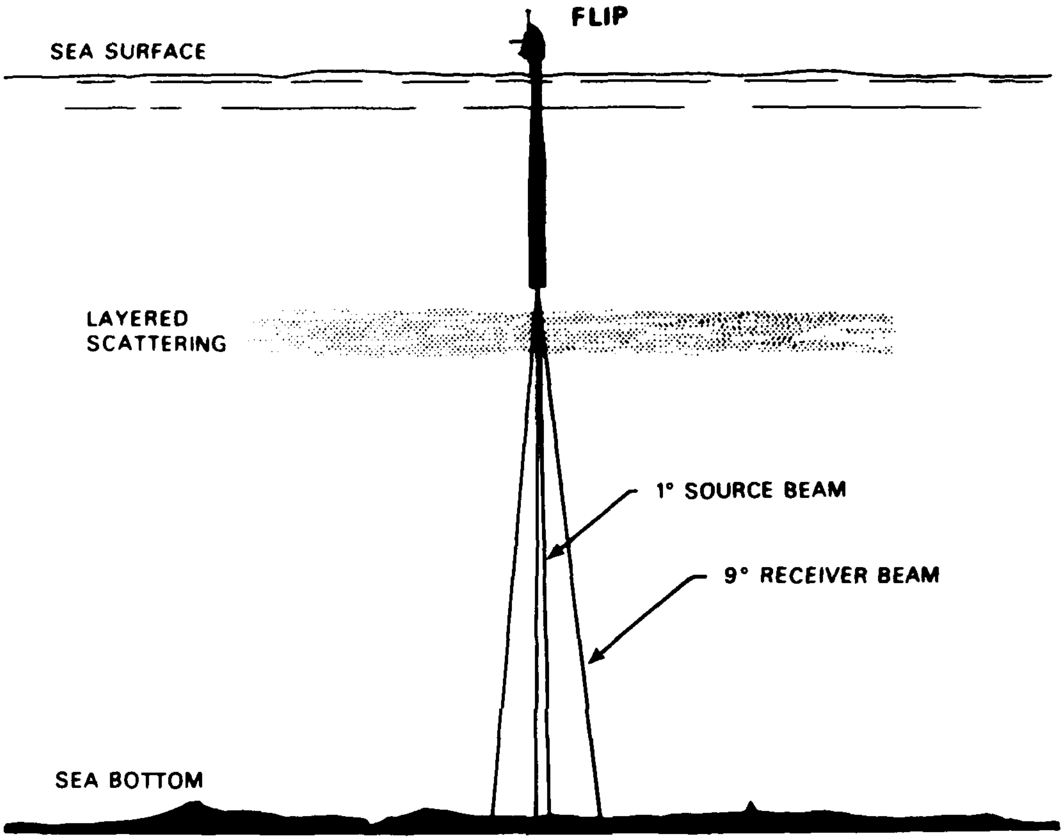


Figure 1. Schematic diagram of echo sounder on R/P FLIP showing scattering layers.

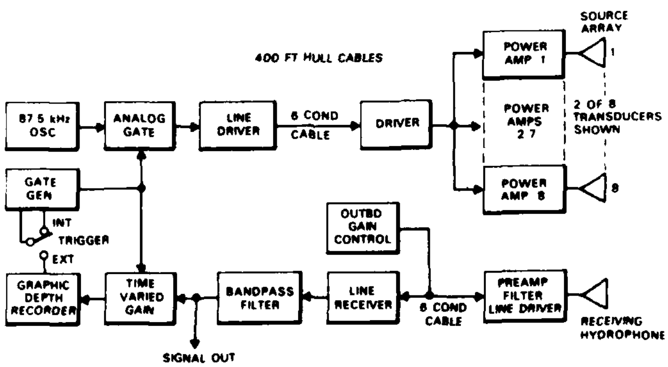


Figure 2. Source and receiver block diagram.

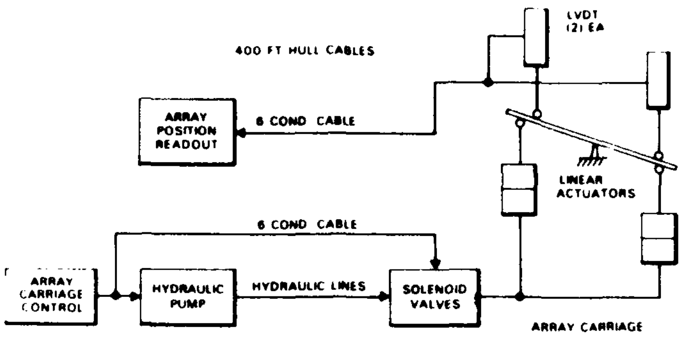


Figure 3. Array position control block diagram.

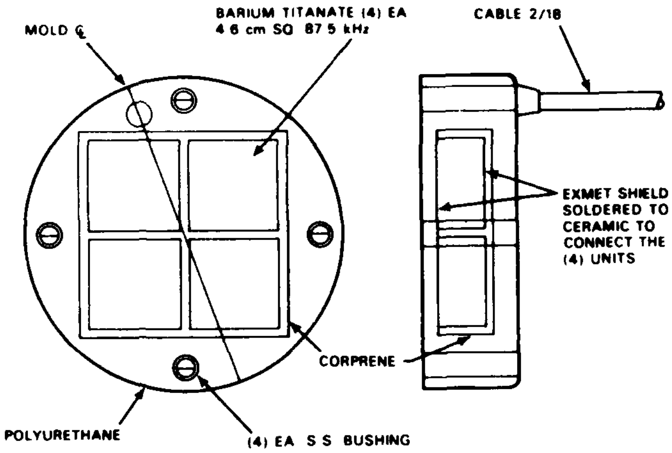
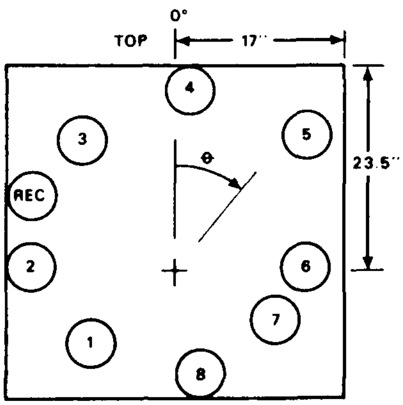


Figure 4. Transducer construction.



XDUCER NO	r	θ
1	13.9"	230°
2	18 6	270
3	18 6	322
4	20.8	1 5
5	20 6	43
6	13 6	98 4
7	11 9	125
8	12 5	173 5
RECVR	19"	296°

Figure 5. Transducer placement on array.

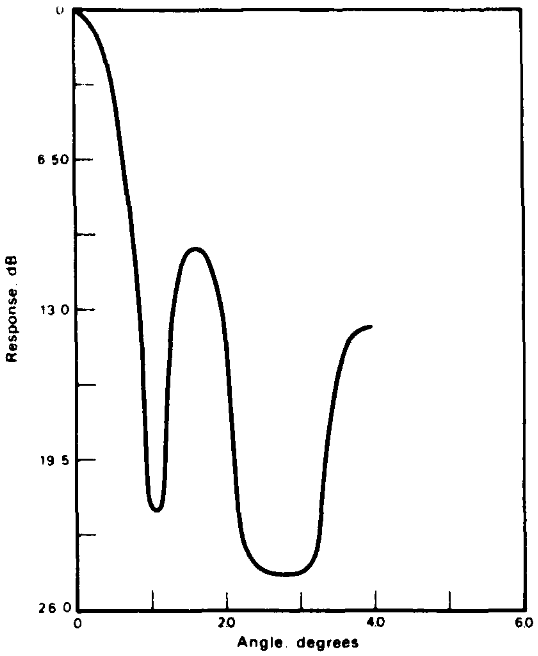


Figure 6. Computer printout of source directivity pattern.

TABLE I

Source Level Calculations

Input power, 400 W		+ 26 dBw
Assume efficiency		- 6 dB
Acoustic power		+ 20 dB
Power to intensity		+171 dB/μPa/w
Intensity per transducer		+191 dB/μPa
Beam width correction) 15° at -10 dB)	$20 \log \frac{360}{15}$	+ 27 dB
Array gain 10 log 8		+ 9
Source level		+227 dB/μPa

Each of the eight transducers is driven by a power amplifier capable of delivering 400 W at 87.5 kHz, in a pulsed mode operation for pulse lengths up to 100 msec. The power amplifiers are driven in parallel producing a source level of +227 dB/μPa (Table I). The source level estimate of Table I is in agreement with a level obtained by extrapolating a measurement made at lower power on a single transducer.

Electrical driving power is provided by an inboard 60 V, 2.5 A regulated supply. A 22,000μ F storage capacitor is provided at each power amplifier. The energy stored by this capacitor is 40 joules. The capacitor is charged through 100 ohms. This time constant of 2.2 sec and the stored energy put a maximum limit on the operating duty cycle of the echo sounder. For bottom sounding work a 3.5 msec pulse at 2 sec intervals was chosen. This is a duty cycle of 1.75% with .7 joule of energy being used.

Though the nominal design frequency was 90 kHz the exact operating frequency was chosen by comparing the driving current phase of each of the eight transducers. A frequency of 87.5 kHz proved to be the best choice, with maximum electrical phase errors of 20° between the various units.

The 87.5 kHz signal is generated by a crystal controlled oscillator which is gated to a line driver and transmitted by cables to the outboard units which contain the power amplifiers for each hydrophone in a separate pressure container. The pulse rate, width and source level are controlled by the inboard electronics in the laboratory. The triggering of the gated pulse can be controlled by an external signal, allowing synchronization with the readout recorder.

In sea water, cavitation occurs at about 1 W/cm^2/atmosphere. The area of each transducer is 90 cm^2 which yields a cavitation limit of 90 W per transducer. For the maximum power of 400 watts for each transducer, the minimum pressure is 400/90 = 4.4 atmosphere which corresponds to a minimum depth of 46 m for safe operation at full power.

2. RECEIVING SYSTEM

The receiving hydrophone is of similar construction to the transducers shown in Fig. 4 with some additional electrostatic shield. The hydrophone unit is mounted on the same array plate as the transducers, Fig. 5. The significant hydrophone characteristics are listed in Table II and the measured receiving hydrophone beam pattern is presented in Fig. 7.

The hydrophone is transformer-coupled to a low noise preamplifier. Diode limiters are used at both the input and output of the pre-amp to reduce the overload caused by the close proximity of the high level source pulse. The pre-amplifier is followed by an 87.5 kHz band pass filter, a remote gain controlled amplifier and a differential line driver all located in a pressure container at the back of the array. A six conductor 400 ft

TABLE II

Receiving Hydrophone (Ser. #11-72)

Sensitivity at 87.5 kHz	-176 dB/μPa
3 dB Beamwidth	9°
10 dB Beamwidth	15°
Directivity Index (20 log $\frac{360}{15}$	27 dB
First side lobe level	24 dB
First side lobe angle	14°
Impedance	300 Ω in series with 4700 pf

TABLE III

Receiver Characteristics

Outboard Gain	Gain	Output Noise	Equiv. Input Noise
1	70 dB	58 dBv	- 128 dBv
2	85	45	- 130
3	100	30	- 130
4	107	23	- 130
Overall bandpass 6.3 kHz		38 dB	
Noise spectrum level 1 cycle band		-168 dB	

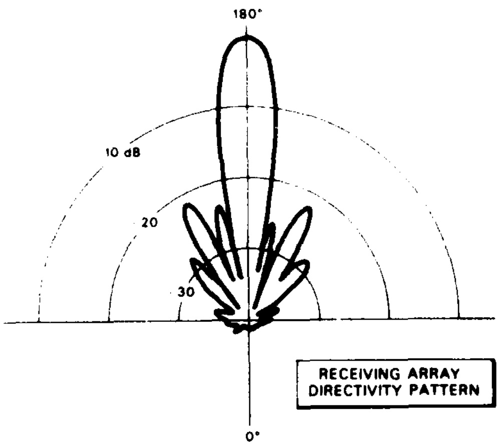


Figure 7. Receiving hydrophone directivity pattern.

cable is used for power and the signal on a balanced line and for remote control of the gain. The inboard receiver consists of a differential line receiver, band pass filter, time varied gain stage and a precision depth recorder (see Fig. 2). The inboard filter output should be used where accurate amplitude information is required. Table III lists the receiver characteristics.

The thermal noise spectrum level for an equivalent input resistor is -173 dBv as compared with the performance measurement of -168 dBv. The noise measured in a calm sea with the array located 86 m below the surface (and pointed down) is at the instrument noise pressure spectrum level of +8 dB/μPa. This is lower than the expected sea surface noise of +12 dB/μPa for a sea state zero.

The bottom return depth resolution is determined by the receiver bandwidth, $t = \Delta d/C = 1/BW$. The 6.3 kHz bandwidth will allow a resolution of $\Delta d = D/BW =$ (1500 m/sec)/ 6.3 kHz = 24 cm.

3. TIME VARIED GAIN

After the first sea test a time varied gain circuit was added in which the gain is increased at a rate that approximates the losses introduced by spherical spreading and absorption (Fig. 8) as reported by Bezdek.[2]

The output of the T.V.G. circuit drives a graphic depth recorder for a display of all echo returns to the system. From Fig. 8 it is seen that the T.V.G. does not fully compensate for the total spreading and absorption loss at the maximum range.

4. ARRAY POSITION CONTROL

The array base plate is mounted on a carriage assembly that can be tilted from the normal vertical beam position by 10° in any direction. This is shown in Fig. 9 mounted at the bottom of FLIP. This allows profiling of a small bottom area. The positioning of the array is by two hydraulic linear actuators controlled by electrically operated solenoid valves. The hydraulic pump is located inboard with pressure hoses running the length of FLIP's hull. The array position angle is monitored by two linear variable differential transformers (LVDT), with inboard readout (Fig. 3). Computer control of the plate will ultimately be included. In this way, the motion of FLIP obtained with an inertial guidance system can be included directly into on line processing to obtain the bottom slope data.

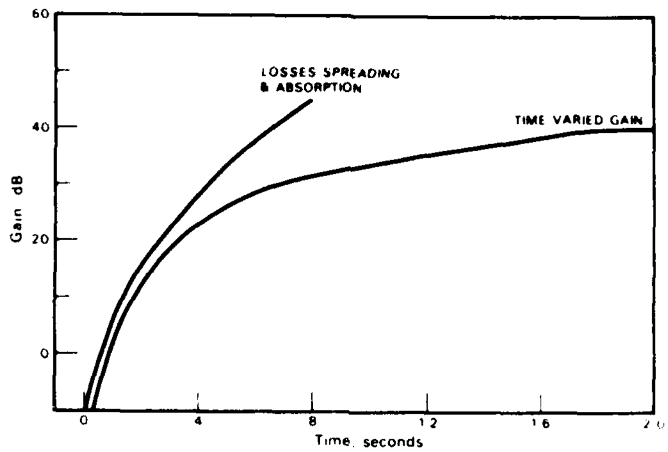


Figure 8. T.V.G. characteristics of receiver system.

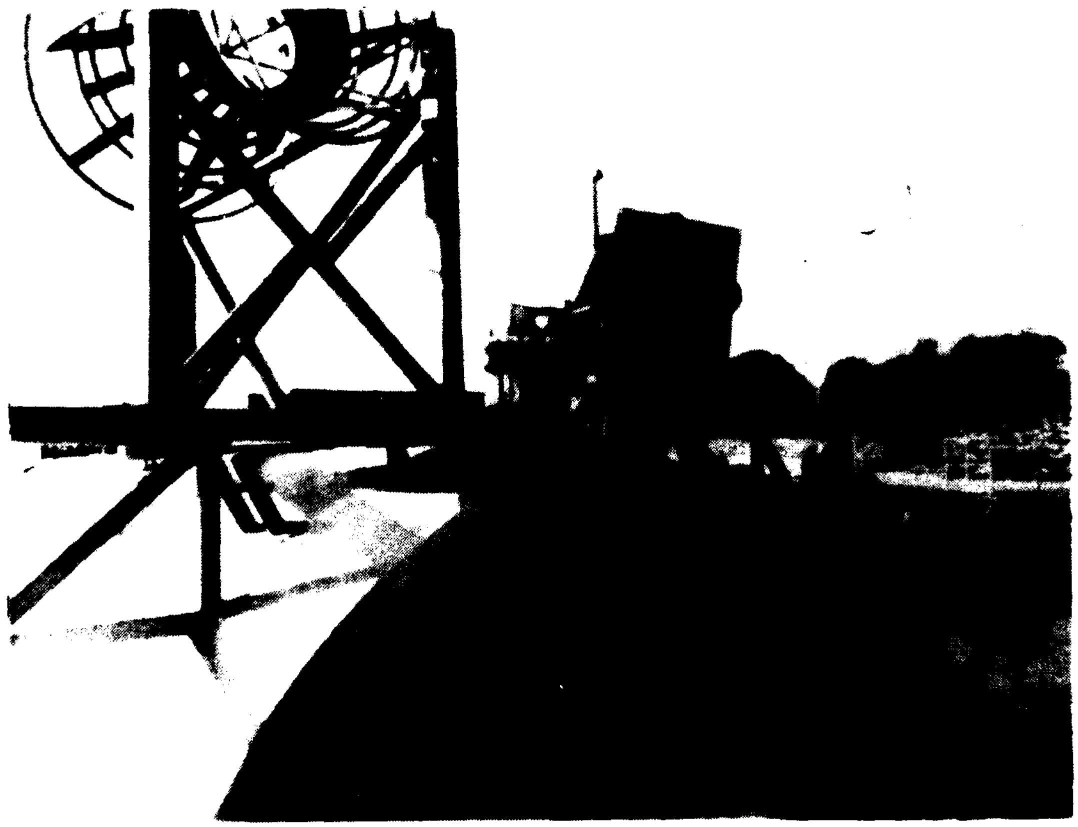


Figure 9. Photograph of array for bottom sounding on bottom of FLIP.

For making measurements of horizontal water velocities in the horizontal looking mode of operation, it was necessary to modify the array. The tilt mechanisms were removed and the array plate was rotated 90° with a hydraulic motor. The array is fixed into the 0° or 90° position by a solenoid operated locking pin. The motor and locking solenoid are powered by the inboard hydraulic pump.

5. COLLIMATOR

With the array in the horizontal mode intersection of the 14° side lobe with the surface is about 360 m from the array. The surface produced strong interference with the main beam which receives energy only from weak scatterers in the medium.

In order to reduce the side lobe response an acoustic collimator was added to the array (Fig. 10). One inch thick sheets of sound absorbing rubber were placed in a series of rings forward of the transducers as well as on the inside of a cylindrical shell between the array plate and the rings. This reduced the interference caused by the receiver side lobes especially when the array is used in a horizontal looking mode.

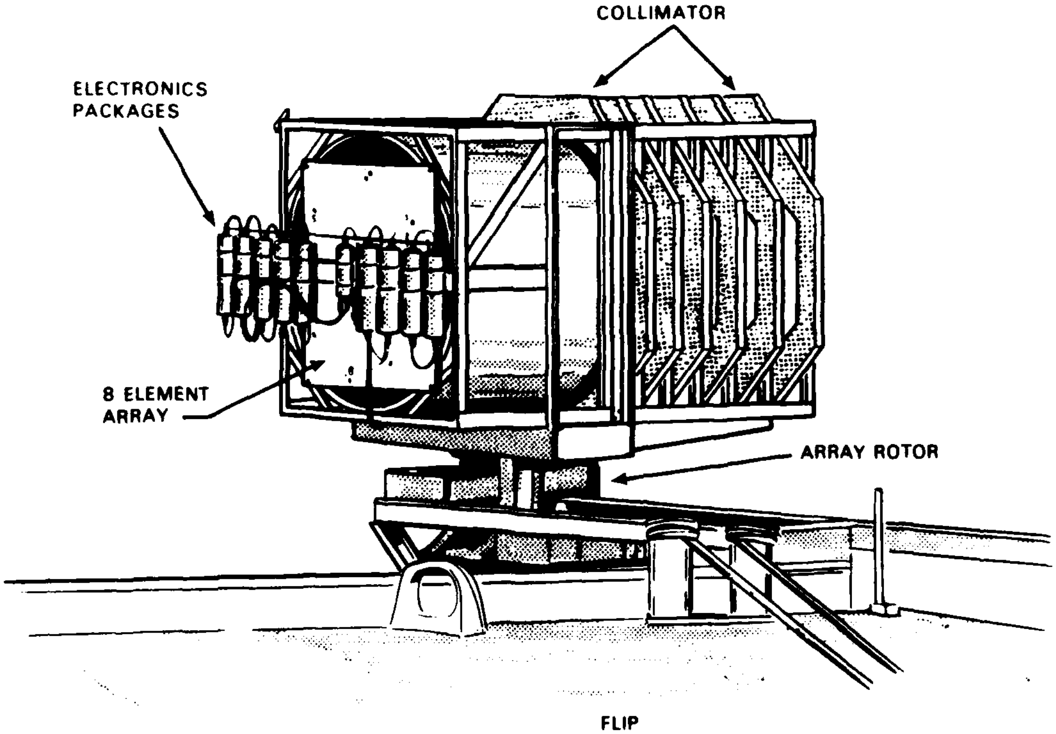


Figure 10. Artist's illustration of echo sounder.

The collimated array as mounted about 5 m from the bottom of FLIP is shown in Fig. 11. To protect the array from wave damage, steel cable tie downs are used. Once FLIP is in the vertical position, explosive cable cutters are activated to free the array for rotation.

6. SOURCE CALIBRATION

The Marine Physical Laboratory's Lake San Vicente calibration facility[3] was used to measure the array source performance. Directivity patterns with and without the collimator were made as well as source level measurements. The array was operated at a depth of 18 m which required limiting the power to prevent cavitation. The calibrated receiving hydrophone was placed 125 m from the array to insure far field measurements.

Beam patterns displayed side lobes at about 1.5° and 3.5° as predicted. The main beam to first side lobe level appeared to be somewhat lower than expected. This may be due

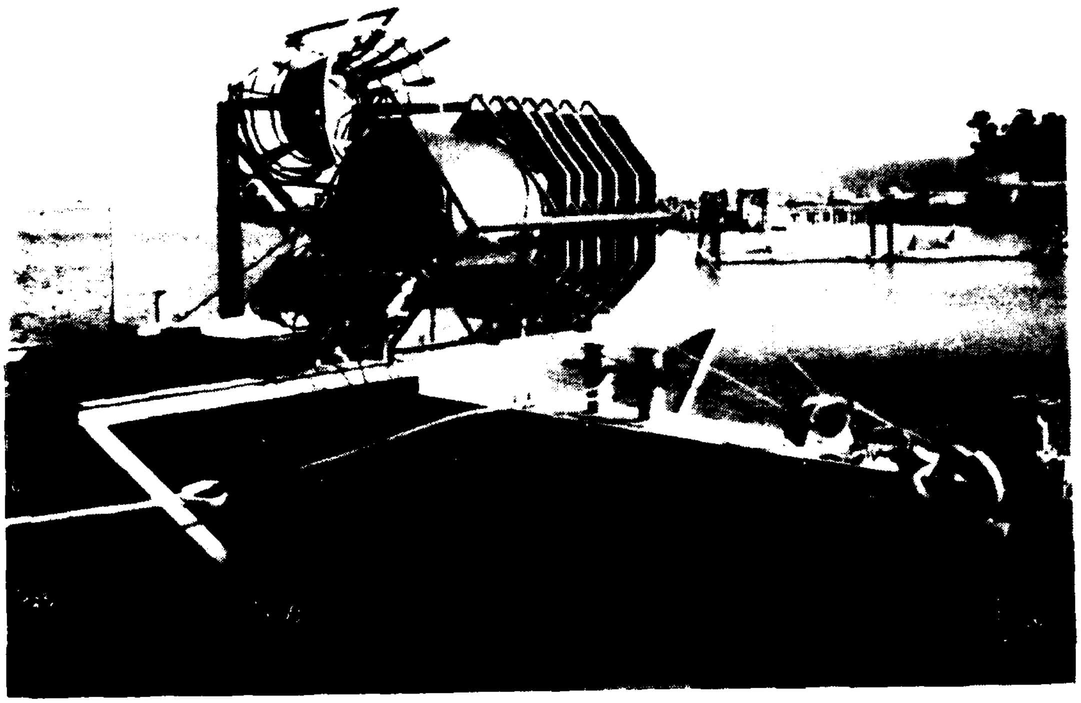


Figure 11. Photograph of array with collimator on FLIP.

to difficulties in maintaining the geometry between the array and receiving hydrophone. Water flow currents in the lake might cause slight tilting of the array, thereby reducing the main beam peak. With 125 m between source and receiver a .5° tilt would result in a 1 m depth error and reduce the received signal level by 3 dB. Figure 12 is an example of the directivity patterns produced by this experiment, the main beam is about 7 dB above the first side lobes.

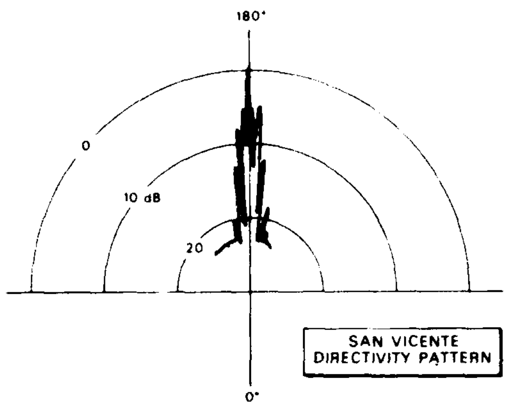


Figure 12. Transmitted beam directivity pattern.

The collimator proved to be quite effective in reducing the level of the side lobes at angles greater than 20° from the main beam. The level reduction is about 20 dB.

The source when operated at the reduced power of 50 watts per transducer produced a source level of +219 dB/μPa. Extrapolating to the normal operating level of 400 watts indicates a source level of +228 dB/μPa which is one dB higher than the estimate of Table I.

II. EXPERIMENTAL RESULTS

1. BOTTOM RETURNS

Echo returns from the bottom are shown in Fig. 13. The reflection coefficient of the bottom was calculated as shown in Table IV.

The measured reflection coefficient of -34 dB is in excellent agreement with a value determined by Bezdek[2/] at 75 kHz in approximately the same area; his measurements were made near the bottom, however, and obtained an average amplitude reflection coefficient of 0.018 corresponding to -35 dB. Note that a weaker(47 dB) echo appears just above the bottom echo. We do not yet know how to explain this echo.

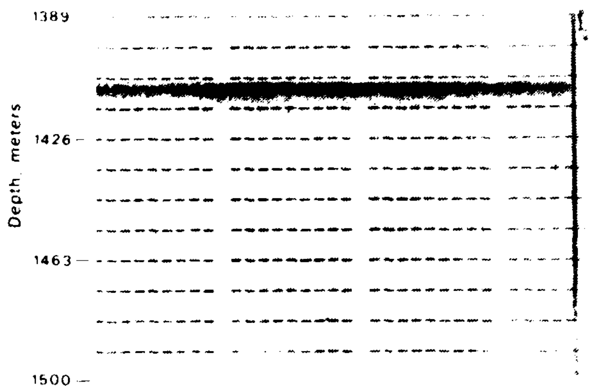


Figure 13. GDR record of bottom reflections.

TABLE IV

Bottom Reflection Coefficient Distance to Bottom 1400 m

Source level	227 dB/μPa
Received spectrum level	66 dB/μPa±3 dB
Spreading loss 20 log (2 x depth)	69 dB
Absorption loss 21 dB/Km[4*/]	58 dB
Reflection coefficient	34 dB±3 dB

*Bezdek did additional work at 90 kHz.

The maximum depth capability estimated from these measurements is given in Table V. For 400 watts electrical power to each transducer and with the present receiver noise input levels, the system is limited to depths of about 2000 m.

A decrease in input noise to the theoretical minimum would add a maximum of 5 dB to the signal to noise ratio. Increasing the source power to 1000 watts per transducer would add another 4 dB. This 9 dB increase in signal to noise would increase the depth capability for bottom echo sounding only to 2200 m, assuming a -34 dB reflection coefficient at the bottom. The increase in range capability is small because of the large absorption coefficient.

TABLE V

Maximum Depth Capability of Present System

Source level	+ 227 dB/μPa
Background noise	+ 8 dB/μPa
Signal to noise 1 cycle band	+ 219 dB
Bandwidth	- 38 dB
Bottom loss	- 34 dB
Net signal to noise	+ 147 dB
Maximum depth	1900 m

2. ACOUSTIC LAYERING AND INTERNAL WAVES

Acoustic echo-sounding recordings have shown the existence of multiple thin layers at depths of from 98 down to 470 m. The record in Fig. 14 was obtained when FLIP was in a three point moor near San Diego 117°24'W, 32°11'N in 1410 m of water during January 1975. The source was keyed with a .6 ms pulse every 2 seconds. For this first operation of the echo-sounder the signals were recorded on a graphic depth recorder without the use of electronic (T.V.G.) compensation for sperhical spreading and absorption. Distinct layering of the backscatter is evident. The individual layers can be followed as they vary in depth with a period of approximately 20 minutes and a displacement on the order of 5 m, suggesting internal wave action. The layer thickness was no greater than 25 cm; shorter pulses are needed to determine if the layers are thinner.

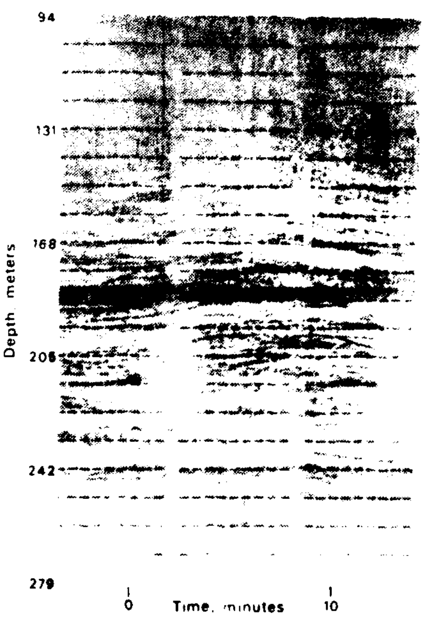


Figure 14. GDR record showing layering and internal wave action.

Initially we reported[4] reflection coefficients for these layers, assuming we were dealing with specular reflection from the layers. One of the problems in analyzing the data is that FLIP's motion makes it somewhat difficult to follow echoes from a particular layer. Subsequent work convinced us that we were, in fact, receiving echoes from individual scatterers populating these layers. That is, even though layers appear to be somewhat continuous on a GDR record we are looking at scatterers which drift through the transmitted beam with a dwell time in the beam corresponding to the relative drift between FLIP and the scatterers.

Target strengths calculated for these scatterers are shown in Table VI. It is seen that the target strength increases with depth.

A scattering layer 20 m thick and at a depth of 250 m, as seen in Fig. 15, remained at a constant depth until 1650 hours, and then moved up passing the array depth of 94 m at 1730 hours.

An oscilloscope trace displayed in Fig. 16 is a portion of a typical received signal showing the variation in amplitude of the returns. The echo level variation observed in Table VI at the depths of 245-284 and 319 meters is evident.

The instrument was operated at sea a second time in May 1975. The first station was at 120°40'W, 30°54'N in 3840 m of water with FLIP drifting in the vertical position. The receiver overload time had been reduced to 17 ms. The time varied gain circuit in use at this time gave a greater usable range to the recorder. Figure 17 shows strong internal wave action. The density of the layering was similar to that observed in January. The horizontal lines are artifacts due to the air-sea surface reflection as seen with a back lobe of the array, and hull reflections because the array was mounted about 5 m above the bottom of FLIP.

A difference in these later records from earlier ones can be noted in the area near the array. This is possible because of the shorter receiver recovery time. Returns

TABLE VI

Layered Scatterers as Observed from FLIP with 87.5 kHz Narrow Beam Echo Sounder

Date	Depth (d) m	Echo Level dB/μPa	Total Losses* dB	Target Strength (Est. error ± 3 dB) dB
30 January 1975	146	94	70	- 63
	169	88	78	- 61
	207	84	87	- 56
	244	79	93	- 55
	319	77	103	- 47
	394	67	111	- 49
26 May 1975	137	97	70	- 60
	179	91	82	- 54
	201	87	87	- 53
	235	80	93	- 54
	310	77	103	- 47
	385	72	111	- 44
29 May 1975	141	88	72	- 67
	160	87	78	- 62
	198	81	87	- 59
	235	77	93	- 57
	310	69	103	- 55
	385	66	111	- 50

Date	Location	Water Depth
30 January 1975	117°24'W 32 11'N	1410 m
26 May 1975	120°40'W 30 54'N	3840 m
29 May 1975	117°32'W 32 29'N	1180 m

* Total losses 2(20 log d) + .021(2d)

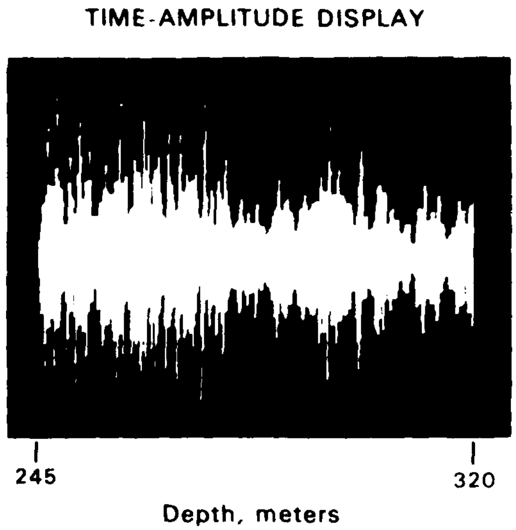


Figure 16. Oscillograph trace showing typical echo returns.

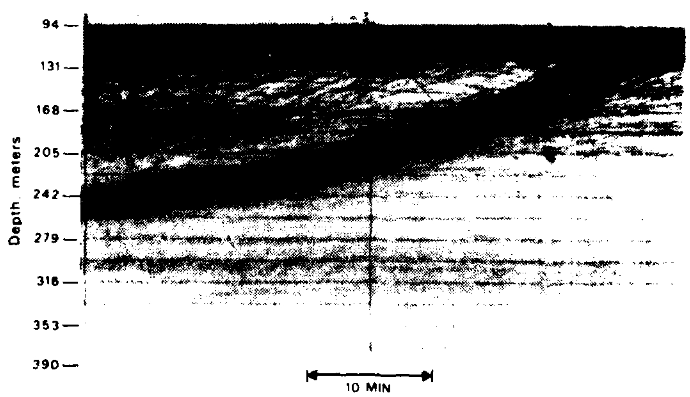


Figure 15. GDR record showing migration upward of deep scattering layer, January 1975.

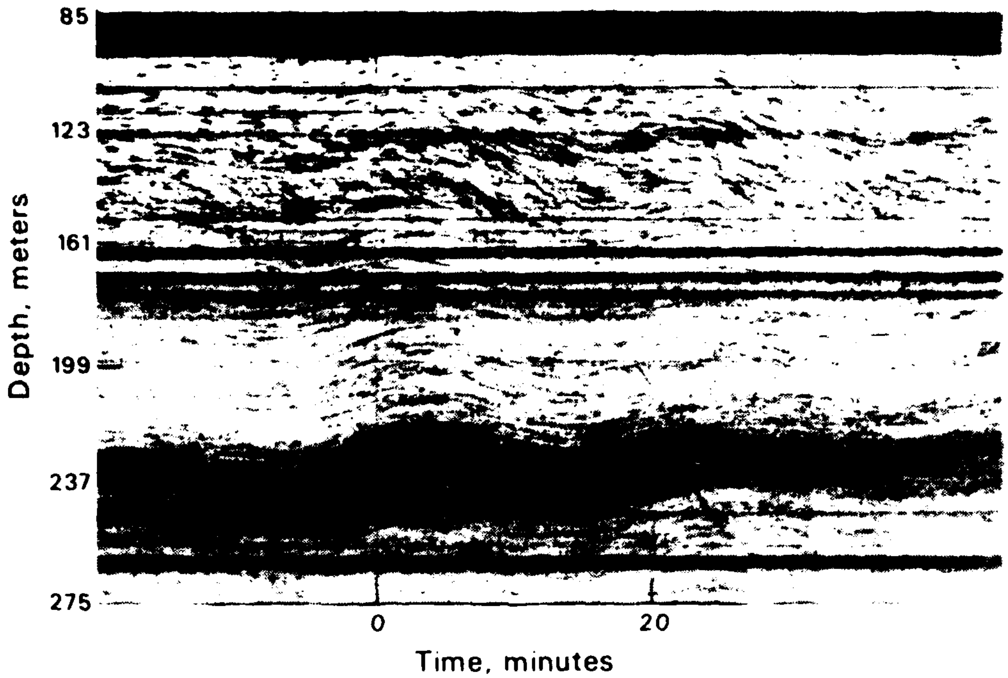


Figure 17. GDR record showing large amplitude internal waves, May 1975.

down to 115 m appear as individual groups. Oscillations at about the 20 minute internal wave period can still be seen at these shallower depths. When observing the returns at close range it should be remembered that the near field range is about 60 m.

Movement of scatterers toward the surface is evident in the recording made between the hours of 1900 and 2000, (Fig. 18); between the hours of 0545 and 0645 the movement is away from the surface (Fig. 19).

Large targets were observed at various times as seen in Fig. 20. They appear to be just under the surface as seen with the back lobe of the array. No explanation is available yet regarding the nature of these targets.

The second station of the May 1975 operation was made at 117°31.5'W, 32°29'N in 1180 m of water. At this location near San Diego, the number of layers was less than that recorded at the deep water station. Figure 21 was made at this location. A scattering layer can be observed moving to deeper water beginning at 0549 hours. Again, some large targets appear for which we have no explanation as yet.

During one phase of the operation the array was turned 90 to a side looking position (Fig. 22). The scatterers can be seen moving away from FLIP. The slope of this movement indicates a relative water current of 15 cm/sec with respect to FLIP along the axis of the transmitted beam.

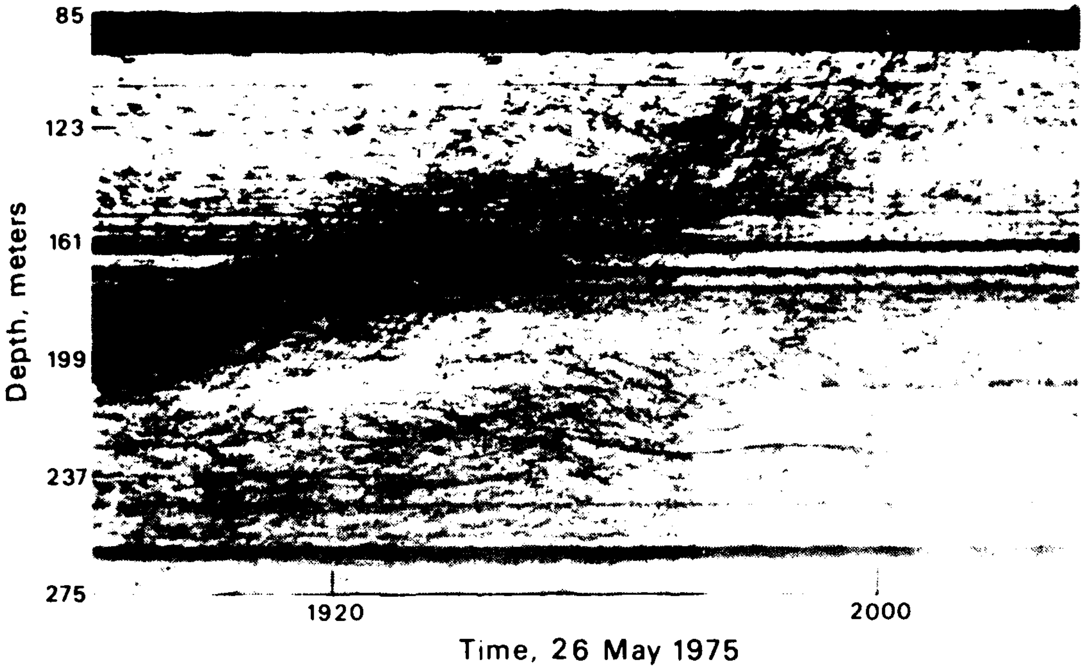


Figure 18. GDR record showing persistence of layers after upward migration of deep scattering layer, May 1975.

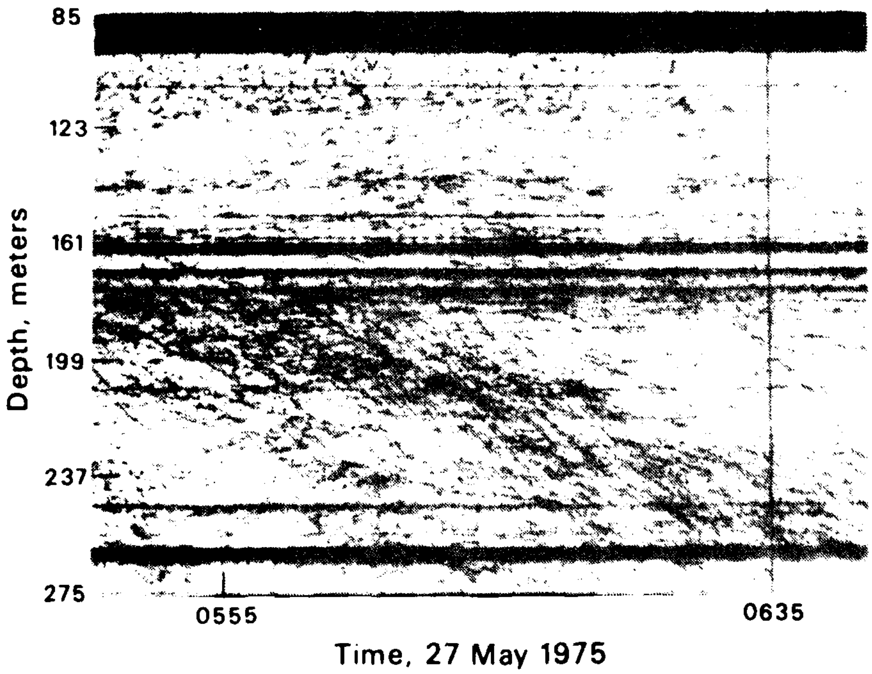


Figure 19. GDR record showing persistence of layers after downward migration of deep scattering layer, May 1975.

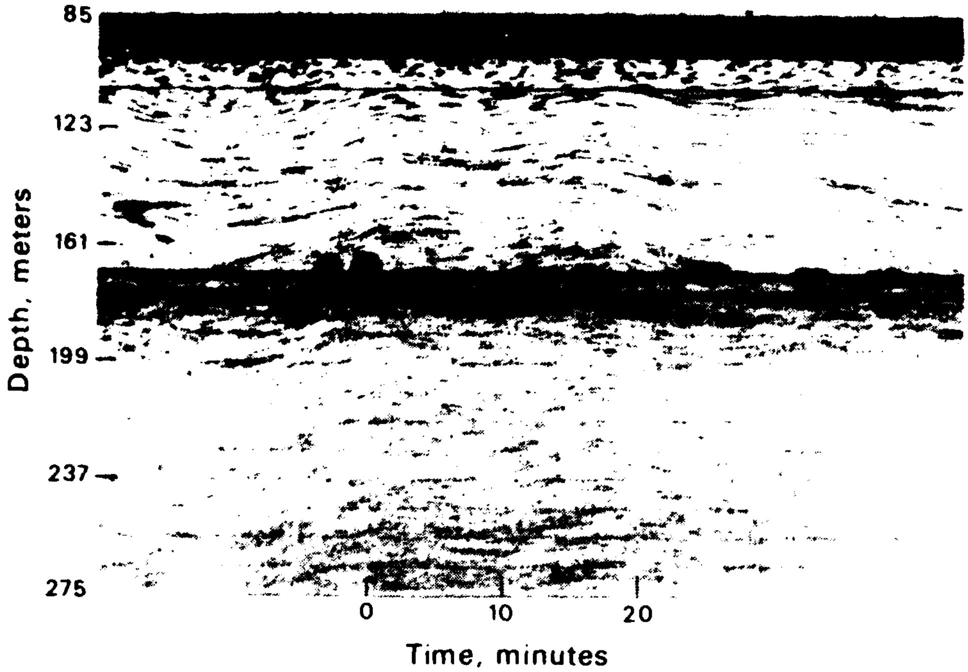


Figure 20. GDR record large echoes of undertermined origin, May 1975.

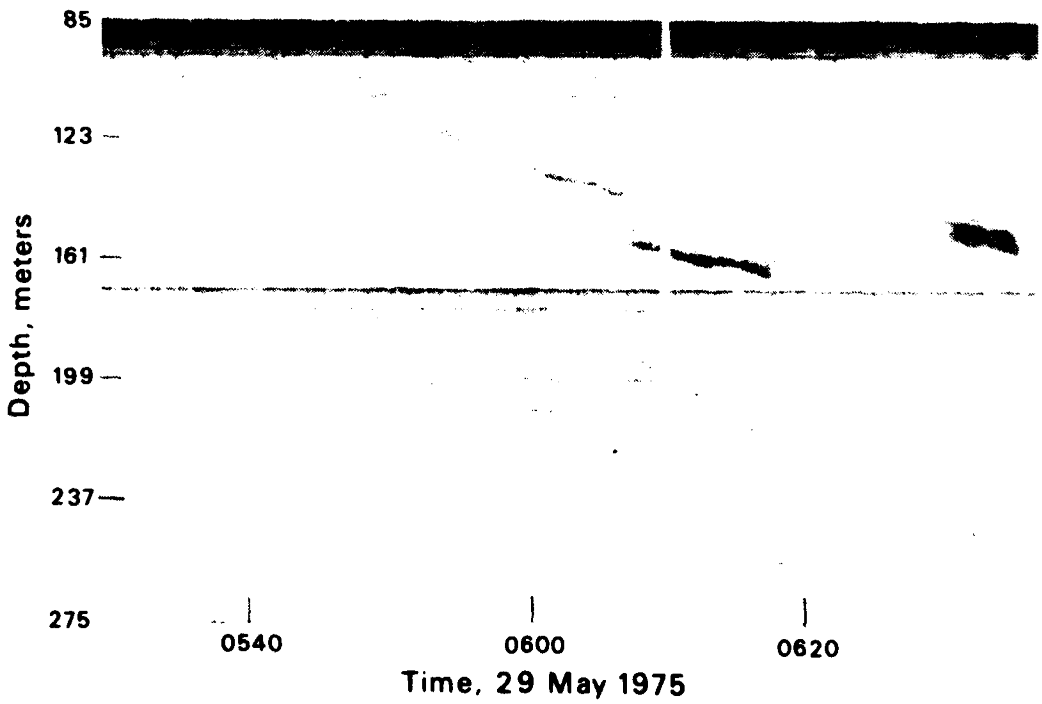


Figure 21. GDR record layer of large echoes of undetermined origin going down, May 1975.

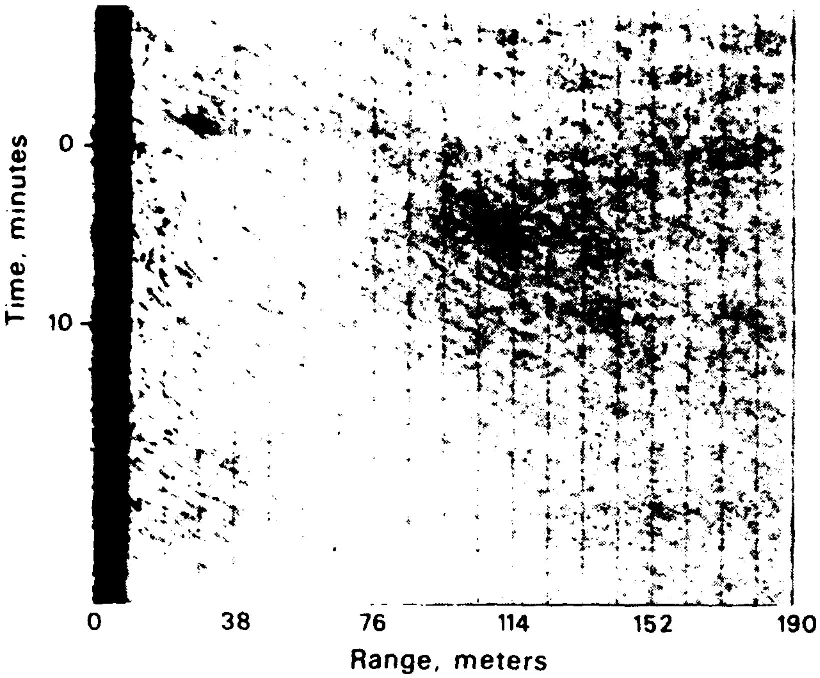


Figure 22. GDR record with array in horizontal mode showing one component of current drift relative to FLIP.

III. CONCLUSION

This instrument was originally developed to fill a requirement for a high resolution bottom sounder. It is presently capable of operating in water with a maximum depth of approximately 2000 m. To obtain a substantial increase in depth capability a multi-element receiving array would be necessary along with an increase in source power as well as a decrease in the receiver background noise.

A second use of the instrument has emerged from data gathered while operating the instrument from the stable buoy FLIP. These data indicate its utility for the observation of layering effects to depths of over 400 m. These returns may be due to density stratification enhanced by suspended particulate matter or organisms.

The development of this instrument was based on new data from experiments on the pressure dependence of sea water absorption by Bezdek.[2] Data obtained from this instrument confirm bottom reflection data also reported by Bezdek.[5]

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This work describes the development of a high resolution echo sounder for use with the R/P FLIP. The instrument has a source level of + 227 dB/μPa, a 3 dB beam width of 1° and a receiver sensitivity of - 176 dB/μPa providing operating capabilities as a bottom sounder for water depths to 2000 m. The results of its operation at sea along with observations of acoustic returns from multiple thin scattering layers to depth of over 400 m are included. Graphic examples under various operating conditions are presented as well as reflection coefficients measured from bottom returns and acoustic scattering target strengths.

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